THE SOURCES AND IMPACTS OF RADIATION

IN THE UNITED STATES

WITH A FOCUS ON PLUTONIUM

An Honors Thesis (HONRS 499)

by

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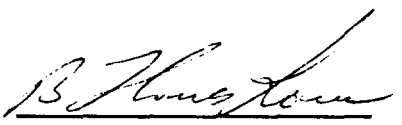

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PROBLEM STATEMENT

The lives of Americans are extremely dependent on energy. Their lives are based on the consumption of that resource in every imaginable facet. When the government realized that the traditional sources of energy such as oil and natural gas were becoming more scarce and coal was becoming somewhat unacceptable due to its contribution to "Greenhouse" gas levels in the atmosphere, the search for alternative sources of energy intensified. This coincided with the promise of the government to use the newly created nuclear capabilities the United States developed to end World War II, in a peaceful manner. In addition, an "energy crisis" in the mid 1970's disturbed the lives of most Americans. The product of all this was the nuclear power industry.

These statements are all true and nuclear power does have the potential to kill many people as do earthquakes, volcanoes, coal mine accidents and vices such as smoking. Undoubtedly more environmentally sound and less dangerous sources of power like solar energy would have been a much better area in which to invest the enormous amounts of money that the government has spent on nuclear power; however, the choice was made to develop nuclear power and it must be dealt with. Environmentalists tend to see nuclear power in only its worst light. It cannot be denied that the industry is laden with problems, but those problems are at times overstated or misunderstood.

This paper will explore the topic of radiation including its sources and impacts. It will cover natural, as well as manmade radiation, detailining dose and possible

health effects. The latter section of the paper will focus specifically on the element plutonium and its potential health effects to society.

OBJECTIVES

This paper is not in support or against the nuclear industry. Its purpose is to evaluate the actual health risks posed by the industry, both weapons and power by comparing those risks to natural sources of radiation including cosmic and terrestrial sources. Also included will be technically enhanced natural sources, medical applications of radiation and occupational exposure.

The question of how large a role the nuclear industry has in the dose to humans, and the effect of that radiation will also be examined. Then due to perceptions about this compound and a large availability of information because it has been studied in depth, plutonium will be the topic of major focus including a chemical description, its concentration in the environment and its relation to induction of cancer in man will be evaluated through the use of human and animal studies. This paper will hopefully clarify the actual role of the element and the nuclear industry and place them in their proper perspectives.

BACKGROUND INFORMATION

RADIATION DEFINED

An atom that is unstable attempts to become stable through the release of energy in several ways, often causing the emission of ionizing radiation. This ionization event transfers energy and causes it to be deposited in the absorbing medium. (Mettler, Moseley p.1). Within the ionizing radiation category there is indirectly ionizing radiation which includes electromagnetic radiation such as gamma, photon and x - rays, and particulate radiation including alpha and beta particle rays which is directly ionizing (Mettler, Moseley p.2). It is the latter which is of particular concern and will be discussed throughout the rest of this report. Alpha emitters deposit their energy in a small region, bathing cells in radiation. They contribute little to the dose to the whole body. Beta emitters are a hazard only to the skin as they cannot penetrate through that barrier.

The unique thing about radiation is that it cannot be sensed by humans in any way. The population is completely dependent upon science and technology to explain and warn about possible dangers. This is perhaps one of the reasons for the emotional nature the public has in regards to radiation.

SOURCES OF ENVIRONMENTAL RADIOACTIVITY

Because people cannot sense this type of energy, they do not realize to what extent they are being bombarded with it daily from the time of conception when the fetus is subjected to most of the radiation that the mother receives. In discussing radiation, sources of exposure are commonly divided into four categories : natural, technologically enhanced, medical and nuclear. Tables 1a, 1b and 1c illustrate the total annual average dose to the U.S. population and the doses to internal organs as contributed from these sources.

Table 1a (Mettler, Moseley p.51)

Annual Average Dose Rates to U.S. Population (1970-1980)

Source	Body Portion	Dose Rate in mrem Prorated over Total Population
Natural Background		
Cosmic radiation	Bone marrow	30
Cosmogenic radionuclides	Bone marrow	0.7
External terrestrial	Bone marrow	35
Internal radionuclides (except radon)	Bone marrow	24
Radon	Segmental bronchi	100–450
Fallout	Whole body	2
Nuclear industry	Whole body	0.3
Research	Whole body	< 1
Consumer products*	Whole body	3–4
Airline travel	Whole body	0.5
Medical		
Medical diagnosis	Bone marrow	77.00
Dental diagnosis	Bone marrow	1.4
Nuclear medicine	Bone marrow	13.6
Occupational	Whole body	0.4
Total		150–200 mrem/yr (radon excluded)

*Tobacco use excluded.

Table 1b (Hendee p.45)

MAJOR SOURCES OF LOW-LEVEL RADIATION EXPOSURE

Source	Dose to Internal Organ (mrem/yr)
Cosmic rays and cosmic ray-produced radioactive elements	29
Radioactive elements in the body	27
Terrestrial	26
Medical	100
Buildings	10-13
Fallout	5
Other technologies	5

Table 1c (Mettler,Moseley p.52)

Annual Estimate of U.S. Population Collective Effective Dose

Source	Man-rems	Man-sieverts
Natural background	24,000,000	240,000
Radon	1,700,000	17,000
Medical radiation	24,000,000	240,000
Nuclear weapons	1,400,000	14,000
Consumer products, building materials	1,200,000	12,000
Nuclear energy	56,000	560
Occupational	150,000	1,500
Total (approximate)	50,000,000	500,000

Natural Radiation

The first category of natural or background radiation which is the largest contributor to the collective dose of the world's population (Mettler, Moseley p.31), includes cosmic rays. Although cosmic rays are not well understood, they are known to consist of approximately 90% protons with the remainder being made up of alpha particles, heavy nuclei and electrons, all of which have extremely high energies. Cosmic rays originate from galactic sources including some solar which are particularly associated with sun spot activity. They are primary energetic particles of extraterrestrial origin that enter the earth's atmosphere. They also result in secondary radiations produced by interactions of the primary particles with the atmosphere.(Kathren p.1) of which only 1/1000 of those striking the earth's atmosphere penetrate to the surface (Hendee p.russell), interact with the nucleus of atoms in the atmosphere and in the earth to produce radioactive isotopes, which are called cosmogenic radionuclides and are listed in Table 2 along with their half lives and global inventory. Humans are exposed to the radiation by the simple process of living.

Table 2 (Kathren p.32)

Principal Cosmogenic Radionuclides.

Nuclide	Half-life	Production Rate (atoms/ cm^2-sec)	Global Inventory (kg)	Air Activity Bq/m^3
H-3	12.26 y	0.25	3.5	0.167
Be-7	53 d	0.08	0.0032	0.017
Be-10	2,700,000 y	0.05	3.9×10^5	10^{-7}
C-14	5760 y	2.5	6.8×10^4	0.067
Na-22	2.6 y	8.6×10^{-5}	0.0019	1.7×10^{-6}
Al-25	740,000 y	1.4×10^{-5}	1000	—
Si-32	280 y	1.6×10^{-4}	1.4	3.3×10^{-8}
P-32	14.3 d	8.1×10^{-4}	0.0004	0.00033
P-33	24.4 d	5.8×10^{-4}	0.0006	0.00025
S-35	87.9 d	0.0014	0.0045	0.00025
Cl-36	380,000 y	0.0011	1.4×10^4	5×10^{-10}
Ar-39	270 y	0.0056	23	—
Kr-81	210,000 y	10^{-6}	16.2	—

Exposures in the U.S., as shown in Table 3, vary according to altitude above sea level. Exposure doubles every 1500 meters above the surface of the earth, which is why the dose rate for people in Denver is twice that of those living at sea level. Dose due to cosmic rays, that is the annual effective dose equivalent to the American population is 30 millirem (mrem). This dose is continuous and constant for a particular area over time, although being indoors does reduce the dose by 20%

Table 3 (Kathren p.30)

Annual Cosmic Ray Dose Equivalents in the United States.

Political Unit	mSv/y	mrem/y	Political Unit	mSv/y	mrem/y
Alabama	0.40	40	New Jersey	0.40	40
Alaska	0.45	45	New Mexico	1.05	105
Arizona	0.60	60	New York	0.45	45
Arkansas	0.40	40	North Carolina	0.45	45
California	0.40	40	North Dakota	0.60	60
Colorado	1.20	120	Ohio	0.50	50
Connecticut	0.40	40	Oklahoma	0.50	50
Delaware	0.40	40	Oregon	0.50	50
Florida	0.35	35	Pennsylvania	0.45	45
Georgia	0.40	40	Rhode Island	0.40	40
Hawaii	0.30	30	South Carolina	0.40	40
Idaho	0.85	85	South Dakota	0.70	70
Illinois	0.45	45	Tennessee	0.45	45
Indiana	0.45	45	Texas	0.45	45
Iowa	0.50	50	Utah	1.15	115
Kansas	0.50	50	Vermont	0.50	50
Kentucky	0.45	45	Virginia	0.45	45
Louisiana	0.35	35	Washington	0.50	50
Maine	0.50	50	West Virginia	0.50	50
Maryland	0.40	40	Wisconsin	0.50	50
Massachusetts	0.40	40	Wyoming	1.30	130
Michigan	0.50	50	District of		
Minnesota	0.55	55	Columbia	0.40	40
Mississippi	0.40	40	Puerto Rico	0.30	30
Missouri	0.45	45	Guam	0.35	35
Montana	0.90	90	Samoa	0.30	30
Nebraska	0.75	75	Virgin Islands	0.30	30
Nevada	0.85	85			
New Hampshire	0.45	45	U.S. Mean	0.45	45

From Klement et al., 1972, p. 10

Table 4 (Hendee p.43)

Cosmic Ray Doses to a Person Flying in Aircraft (Dose/Round-Trip)

Route	Subsonic Flight μGy (mrem)	Supersonic Flight μGy (mrem)
Los Angeles-Paris	48 [4.8]	37 [3.7]
Chicago-Paris	36 [3.6]	26 [2.6]
New York-Paris	31 [3.1]	24 [2.4]
New York-London	29 [2.9]	22 [2.2]
Los Angeles-New York	19 [1.9]	13 [1.3]

Adapted from Wallace R: Measurements of the cosmic radiation dose in subsonic commercial aircraft compared to the city-pair dose calculation, Lawrence Berkley Laboratory Report #1505, 1975.
Under normal circumstances without solar flares.

This is a source of concern also to people traveling at high altitudes such as flight crews and astronauts. A round trip cross country airplane trip at 35,000 feet incurs a dose of 2 to 5 mrad(millirad) or about 2 mrem, as Table 4 shows. A typical airline crew can expect an annual effective dose equivalent from cosmic rays of 80 mrem.(absorbed dose of 160 mrem/year) (UNSCEAR 1982, Hendee p.31)

Astronauts also receive high doses, particularly in times of intense solar activity. Absorbed dose rates of astronauts on the Apollo space mission and lunar landing have been in the range of 1 mrem/hour and may increase by a factor of 2 or 3 due to solar activity. (Mettler, Moseley p.43) The astronauts on the circumlunar mission, Apollo X received up to a dose of 410 mrads.(UNSCEAR 1982)

The major contribution of natural radiation to exposure of the average U.S. citizen is due to terrestrial radiation which encompasses both internal and external exposure. Natural constituents of cells may be radioactive. The doses incurred are due to primordial radionuclides which have existed in and on the earth since its formation. Those that still remain have half lives of 4.5 x 10 (9) (4.5 trillion) years, comparable to the age of the universe. These are present in detectable amounts, but the majority of the dose to humans comes from the decay of these radionuclides to other nuclides. Although there are 22 different types as seen in Table 5 on the next page, only Potassium (K)-40 and Rubidium (Rb)-87 are of any biological significance. Potassium is the major source of internal dose. It is found in all living things and formerly living things including rocks, soil and seawater. The average human of 154 pounds(70 kg) contains about 140 grams of potassium, mainly in muscle tissue. (ICRP 19, 1976) (Kathren p.42) The dose of K-40 to tissues within the body is 19 mrem.

Table 5 (Kathren p.40)

Primordial Singly Occurring Radionuclides.

Nuclide	Half-Life (years)	% Isotopic Abundance	Decay Mode	Energy (Mev)
K-40	1.3×10^{9}	0.0118	Beta	1.32
V-50	6×10^{14}	0.25	Beta	—
Rb-87	4.7×10^{10}	27.83	Beta	0.273
Cd-113	9×10^{15}	12.3	Beta	—
In-115	5×10^{14}	95.7	Beta	0.49
Te-123	1.2×10^{13}	0.87	EC	—
La-138	1.1×10^{11}	0.09	Beta	0.27
Ce-142	$>5 \times 10^{16}$	11.1	Alpha	1.5
Nd-144	2.1×10^{15}	23.9	Alpha	1.83
Sm-147	1.1×10^{11}	15.0	Alpha	2.23
Sm-148	8×10^{15}	11.2	Alpha	1.95
Sm-149	$>10^{16}$	13.8	Alpha	<2.0
Gd-152	1.1×10^{14}	0.20	Alpha	2.14
Dy-156	2×10^{14}	0.06	Alpha	3 (?)
Lu-176	2.7×10^{10}	2.6	Beta	0.57, 0.31
Hf-174	2×10^{15}	0.17	Alpha	2.50
Ta-180	$>1.6 \times 10^{13}$	0.012	Beta	—
Re-187	5×10^{10}	62.5	Beta	0.0026
Pt-190	7×10^{11}	0.013	Alpha	3.16
Pb-204	1.4×10^{17}	1.48	Alpha	2.6

Data from Lederer et al. (1977), *Table of Isotopes.*

The significance of other nuclides is minimal. Through decay chains (Uranium, Thorium and Actinide chains) the thorium and uranium found within humans is produced. For example, a typical man will contain approximately 100-125 ug (micrograms) of uranium which originates from ingestion of food. Daily intake approximates 1 ug with some excretion through feces. (Mettler, Moseley p.34) The uranium is mainly contained within the bones, however, the dose to the bones is still extremely low (less than 1 mrad). Therefore it has little significance to health.

Geographic location is also a factor due to the content of different rocks and soils in the area. For example the thorium concentration in the monazite sand in Kerala, India is the highest anywhere in the world. The absorbed dose to the 70,000 people living in the area is 2.3 x 10(4) rads/hour. Thorium is chemically similar to calcium so it concentrate in the bone. (Mettler, Moseley p.36) Due to the soil composition in France, seven million people experience terrestrial radiation amounting to 300 mrem. (Hendee p.42) In parts of the Soviet Union the dose can reach 70,000 mrem/yr.

Radium, found in rocks, soil and water, decays into radon, a gas which has received much publicity in the past few years, is an important aspect of terrestrial radiation. The most concern has been given to indoor concentrations in homes which can sometimes reach dangerously high levels. Radium is also readily taken up by plants so humans may receive part of their dose through food consumption. The amount of radium in soil is dependent on location.

Overall the total external and internal sources of terrestrial radiation in the United States amounts to an average of 53 mrem/year, although this figure is twice as high in the Rocky Mountains. (Hendee p.42) When included with radiation exposure due to cosmic rays of about 30 mrem, natural radiation accounts for nearly 50% of the radiation exposure Americans receive.

Technology Enhanced Radiation

This type is basically a form of natural radiation that has been modified. It occupies a much smaller percentage of annual dose. The exposure is brought about by using materials for other purposes such as mining and milling of radioactive metals, the mining of phosphates for fertilizer for which gypsum is the main contributor to dose. (Mettler, Moseley p.41)

Building materials such as stone and brick contain K-40, Ra-226 and Th-232 in addition to radon. Granite can result in dose of a few tenths of a mrad/hour. The average whole body dose in masonry buildings are at least 13mrem/year, whereas in wood frame houses, the dose would be less than 10 mrem. (Hendee p.42) These are significant to a small degree when such materials are present and uncovered to a great extent in houses.

Also within this category is included the burning of fossil fuels. This is due to the dispersion of the primordial radionuclide K-40 which coal has more of than any other radionuclide and the fact that coal produces a significant amount of particulates. Radiation released from a coal fired plant poses 410 times the health threat that radioactive emissions from a nuclear power plant of the same size. (Hendee p.238)

The amount of radionuclides within the fly ash is greater than that in the actual coal. (Mettler, Moseley p.41) The Powder River Basin Coal in the Western United States contains several 100ppm of uranium, whereas Eastern coal averages 10ppm or less.(Kathren p.78) The effect that the burning of coal is difficult to estimate due to the highly variable amount that is burned and the different types of coal used. The best estimate is 200 manrem for each gigawatt of energy generated. Worldwide effective dose equivalent commitment has been estimated at 10 (7) man rem. (Mettler, Moseley p.41) The whole body dose to people residing in the area of a large coal fired plant could run as high as 100 mrem per year.

Another way man is exposed to technologically enhanced radiation is through consumer products, as evidenced in Table 6 on the next page. A once popular use of radium is within watches and clocks to make them luminesce. Older timepieces can give doses up to 2.5 mrem if worn continuously. Now tritium has replaced radium and the dose is negligible. (Kathren p.79)

Electronic equipment such as televisions and others machines with cathode ray tubes such as video display terminals, particularly older models are a source of radiation. Assuming use of six hours a day, five days a week and fifty weeks of the year, the annual radiation dose to individuals that were **two** inches from the

screen that is emitting the typical .1 mrad per hour is 150 mrem. The two inches was used as an extreme. The dose was found to decrease dramatically as the distance from the screen increased.

Table 6 (Hendee p.42)

RADIATION FROM CONSUMER PRODUCTS		
Product	Dose (mrem/year)	Portion of Body Considered
Luminous wristwatches	1-3	Gonads
Television sets	0.3-1	Gonads
Coal combustion	0.25-4.00	Lungs
Oil combustion	0.002-0.004	Lungs
Gas ranges	6-9	Lungs
Tobacco products	8,000	Lungs
Uranium in dental porcelain (dentures and crowns)	60,000	Superficial layers of tissue in contact with teeth
Eyeglasses	1,000-4,000	Germinal cells of the cornea
Smoke detectors	0.03-1.5	Whole body

Data from National Council on Radiation Protection and Measurements Report No. 56, pp 55-57, 1977.

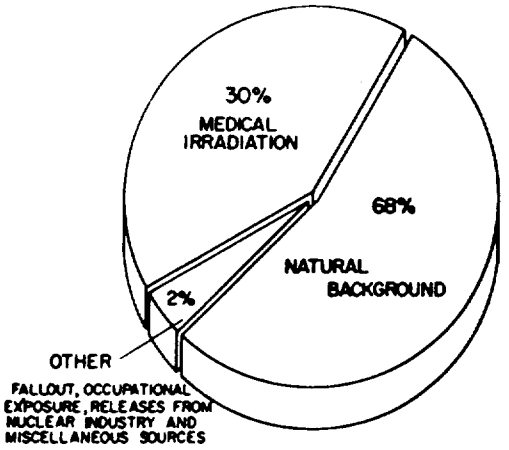
Tobacco products contribute an extraordinary amount of radiation dose due to the fact that the dose is so localized. The radionuclide of significance is mainly lead(Pb)-210 and the majority of damage is done to the bronchial epithelium. (Mettler, Moseley p.45) Smoking 1.5 packs a day will contribute 8000 mrem/year to small areas of the bronchial lining. This figure represent 80 times what the absorbed dose would be due to inhaling. Researchers believe that this may be part of the cause of lung cancer.(Hendee p.43)

Even eye glasses contribute 1000 to 4000 mrem per year to a few millionths of an inch of the eye. Reading also contributes .0005 mrem/hour to the eyes. Fortunately, the tissues absorbing the dose are relatively insensitive. (Hendee p.43) Despite these large numbers, the contribution to whole body dose is less than 5 mrem. (Hendee p.43)

Medical Radiation

The medical field also provides a source of radiation exposure. In fact, in highly developed countries as referenced in Figure 1, the contribution of medical radiation to dose has exceeded that of natural background as a radiation source. (Mettler, Moseley p.42) Medical applications of radiation are typically divided into three categories which include 1)nuclear medicine, 2)diagnostic x-rays and 3) radiation therapy. There are differences in this exposure compared to other types, specifically because the radiation is delivered to only a portion of the body at a very high dose rate.

Figure 1 (Hendee p.32)



Nuclear medicine involving the use of radiopharmaceuticals in the U.S. has grown rapidly within the past two decades. UNSCEAR 1982 estimated that in developed countries it contributes 15,000 man rem for each million of total population. (Mettler, Moseley p.20). Diagnostic x-rays on the other hand, contribute 100,000 man rem per million in the population. Medical x-rays, being most common, contribute very little to each person, but due to the large amount of x-rays performed, their collective dose rates are high.

The final category is radiation therapy which has been used to treat malignant tumors. The doses are in the range of 5000-7000 rads and are applied over five to six weeks. While the radiation is significant to the individuals receiving treatment, overall the radiation produced by medical applications is very small to the overall population.

Occupational Exposure

This is of limited importance to the dose to the general population, as certain occupations are more at risk than others as illustrated in Table 7. In the U.S., there are about 1.3 million people who could be potentially exposed, but only half receive any measurable dose. The total annual collective dose equivalent for workers is 150,000 manrems. As far as individual dosage is concerned, about 80% receive an annual dose equivalent of less than .1rem, 95% receive less than 1 rem and 99.9% receive less than the allowable limit of 5 rem. (Mettler, Moseley p.47) The .1% suffer greater dose due to accidents. Again, this source is applicable to only those within occupations at risk.

Table 7

(Mettler,Moseley p.47)

Annual Average Doses and Collective Dose Equivalent from Occupational Exposure

Occupation	Average Exposure		Annual Collective Dose Equivalent by Million Population
Uranium miners	13 mSv	(1.3 rem)	
Power reactor workers	5 mSv	(500 mrem)	
Fuel reprocessing workers	10 mSv	(1 rem)	
Total nuclear power cycle			0.5 man Sv
Diagnostic radiology workers	< 1 mSv	(< 100 mrem)	
Radionuclide teletherapy	2 mSv	(200 mrem)	
Total medical care			1.0 man Sv
Airliner crews	1-2 mSv	(100-200 mrem)	
Enhanced exposure to natural radiation (especially while flying)			1.0 man Sv

From Kumazawa and Nelson.[21]

Nuclear Industry

NUCLEAR WEAPONS/FALLOUT

People may not realize that they are receiving doses from any of the aforementioned sources, however they do know that nuclear power is, or at least has the potential to be, a source in their life. Americans are in fact exposed to some radiation due to fallout and nuclear power, but that exposure is nowhere near the dosage from natural and medical sources.

History

Nuclear weapons testing and use is the reason for radioactive fallout that continues to drift around our atmosphere. The history of nuclear use for weapons dates back to President Franklin Roosevelt's administration which established the Manhattan Project, an intense research and development program to produce an atomic bomb. On July 16,1945, the first nuclear weapons test took place near Alamogorde, New Mexico. A month later, the first atomic bomb was dropped over Hiroshima, Japan. The United States detonated a total of four more test devices in the next three years, followed by testing by the USSR and Great Britain. In 1958 a moratorium on nuclear testing began, but 250 known nuclear explosions with a yield of 32 megatons had occurred in the atmosphere worldwide. (Kathren p.95) In 1962, the Limited Test Ban Treaty was signed by all countries with nuclear weapon capabilities except for the USSR who has ignored the treaty. France, China and India delayed, but all three finally signed by 1974. These countries all continued to test above ground until they agreed to the treaty. In the U.S., most testing has been

done in Nevada and the Pacific Proving Grounds including Eninetok and Bikini Atolls, Johnston Island and Christmas Island, in areas of little population.(Kathren p.95)

As of 1982, 450 atmospheric and 1000 underground nuclear explosions had occurred. The latter pose little threat if well contained, although some "venting" does occur. (Mettler, Moseley p.45) The yield of the underground tests is less than 80 megatons. The U.S. has the most atmospheric detonations(193) and has produced 139 megatons. The USSR has produced an atmospheric yield of 358 megaton; the United Kingdom, 16 megatons; France 12 megatons; and China, 21 megatons for a worldwide total atmospheric yield of 546 megatons.

Dynamics of Weapons Testing

The actual nuclear explosion consists of a very rapid release of energy caused by nuclear fission or fusion in a small volume, which last only a few milliseconds while releasing an enormous amount of energy. Uranium 233,235 or plutonium-239 may all be used as fission material. Formation of fallout occurs at the height to which the fireball from the explosion rises. This height is dependent on the explosive yield from the device. For example the cloud from a 1 megaton bomb would rise to about 14 miles after 6.3 minutes (1 p.98). Initially, it rises at the rate of a few hundred miles per hour, but then slows as it cools. When the cloud reaches the top of the troposphere, about 50,000 feet, it begins to spread out to resemble the infamous mushroom cloud shape. This cloud will continue to rise up to perhaps 25 miles in the span of 10 minutes after detonation. Within less than an hour, the

cloud spreads outward to 100 miles. (Government of India 1958, Kathren p.98)

The afterwinds, created as the cloud rises and cool air flows into the hot cloud, carries surface debris and dust which the fission products may attach to if the fireball touches the ground, creating a majority of the fallout. Within a minute of detonation, particles are formed containing aluminum and iron oxides. The large particles, containing much less radioactivity, settle out within 100 miles of the detonation, producing local fallout. As stated above, this is typically not considered in dose assessments. The smaller particles which represent most of the volatile fission products, remain suspended in the air for much longer periods of time and fall out up to a few thousand miles away. If the explosion is only 1 kiloton or so, most debris will falllout with a few months. (Kathren p.99). This, considered tropospheric fallout, contains radionuclides detailed in the following section.

Current estimates hold that the world inventory of nuclear arsenals is 40,000 weapons with a total yield of 13,000 megatons, with each weapons containing 4 kilograms of plutonium. Weapons testing cause exposure to the general population through fallout. The estimates of fallout exposure do not consider the local/tropospheric fallout over an area, such as that over Nevada. The estimates just cover stratospheric worldwide fallout.

The particles in the stratosphere have been found to produce a specific worldwide pattern of fallout. Although due to little mixing between hemispheres, the fallout stays within the respective hemisphere in which the bomb was detonated; therefore, the northern hemisphere has a higher exposure rate. The particles tend to remain in the stratosphere for at least a year; however, once the debris reaches the troposphere, it falls out within a month. (Kathren p.100)

Significant Radionuclides

Although more than 300 fission products are induced by nuclear explosions, few have biological or environmental significance due to their very short half lives. Those elements of concern are Krypton-85, Tritium, Carbon-14, Manganese-54, Iodine-131, Iron-55, Strontium-89.90, Ruthenium-106, Cesium 136,137, Barium-140, Serium-144 and plutonium and other transplutonic elements, as listed in Table 8 with their collective dose equivalent to the world's population. (Mettler, Moseley p.45)

Table 8

(Mettler,Moseley p.46)

note: 1Sv = 100rem

1 Bq = 37pCI

Collective Effective Dose Equivalent Commitment to the World's Population from Various Radionuclides in Fallout

Radionuclide	Estimated Stratospheric Input		Collective Effective Dose Equivalent Commitment	
Tritium (hydrogen 3)	2.4×10^{20}	Bq	1.9×10^{5}	man Sv‡
Carbon 14	220	PBq*	2.6×10^{7}	man Sv
Manganese 54	5.2	EBq†	130	man Sv
Iron 55	2	EBq	3.10^{4}	man Sv
Krypton 85	160	PBq	20	man Sv
Strontium 89	90	EBq	3.2×10^{3} (ingestion)	man Sv
			5.8×10^{3} (inhalation)	man Sv
Strontium 90	600	PBq	2.8×10^{4}	man Sv
Ruthenium 106	12	EBq	9.6×10^{4}	man Sv
Iodine 131	700	EBq	1.1×10^{5}	man Sv
Cesium 137	960	PBq	1.2×10^{3} (inhalation)	man Sv
			6.9×10^{5} (ingestion)	man Sv
Cesium 136	7×10^{18}	Bq	190	man Gy
Barium 140	720	EBq	670	man Sv
Cerium 144	30	EBq	1.2×10^{5}	man Sv
Plutonium 238	0.33	PBq	0.3×10^{4}	man Sv
Plutonium 239	7.8	PBq	10×10^{4}	man Sv
Plutonium 240	5.2	PBq	6×10^{4}	man Sv
Plutonium 241	170	PBq	3×10^{4}	man Sv
Americium 241	Unknown		2×10^{4}	man Sv

Adapted from UNSCEAR, 1982.[1]
*PBq = peta becquerel.
†EBq = exa becquerel.
‡man Sv = man sievert

Krypton-85, with a half life of 10.76 years is uniformly dispersed throughout the atmosphere a few years after detonation. Worldwide concentrations due to nuclear explosions(which is only a small portion of the total global inventory) is estimated, as of 1983 to be 3.2 megacuries. The primary concern for external exposure is to the skin from immersion. (Kathren p.104) However, the dose to the skin at a typical concentration of a few picocuries(pCi)/liter is very small : only 21 urad over a lifetime. (UNSCEAR 1982)

Strontium-89 with a half life of 50.5 days is of primary concern only in its uptake in cows milk and obviously with its short half life most of the activity occurs initially. Due to its 28 year half life, Strontium-90 is of greater significance. It is of concern due to its uptake by plants and animals, where it finds its way to people through milk. More than half of the Sr-90 in the northern hemisphere is found in the first 4 cm depth of soil (UNSCEAR 1977). Strontium is much like calcium and therefore concentrates in the bone where it gives its highest dose.

Iodine-131 with and 8.05 day half life is important because of its deposition in foliage and ingestion by animals such as cows in which, like Strontium is passed up through the food chain.

Cesium 137 has a 30 year half life and is found in the top few centimeters of soil and in the ocean. It is found in foodstuffs with concentration ranging from 1 to 2 pCi/kg in fruits and vegetables to up to ten times that concentration in meats, dairy products and grain products due to biological magnification. (Kathren p.109) Doses were of course greater when testing was actually in progress; the estimate now is approximately a whole body dose of about 1 mrad (Kathren p.110).

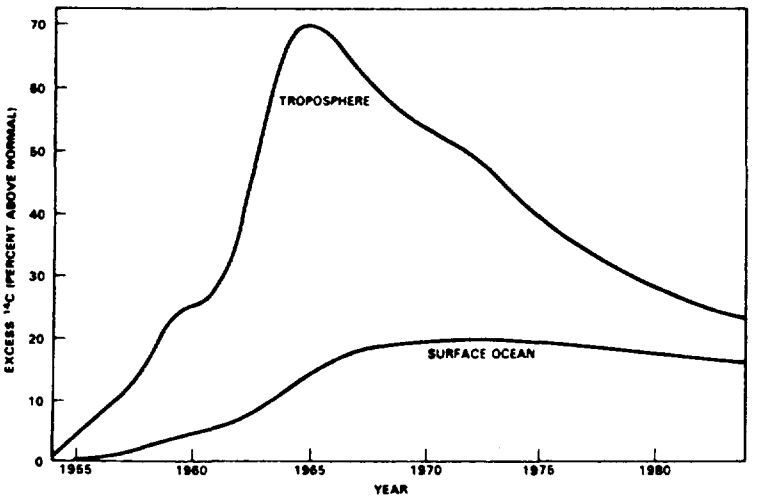
Tritium, with a half life of 12.3 years, is estimated to be present in the atmosphere at a concentration of 8 x 10 (9) Ci with approximately 90% of this from weapons testing. It may stay suspended in the atmosphere or be precipitated to earth. Therefore it can be found on land and in surface waters, whereby it finds its way into all living things. (Kathren p.111) Without a doubt, weapons testing has greatly increased the global inventory. At peak testing in 1963, Tritium concentration in streams in the U.S. were found to be up to 400 times the naturally occurring tritium concentration, and as of 1983 concentrations were still an order of magnitude greater than natural levels. (Kathren p.111) At peak testing, the mean dose commitment due to tritium to people in the northern hemisphere was 2 to 3 mrad. The dose rate to man reached it maximum in 1963 at .2 mrad. By 1979 it had dropped to .01 mrad annually. (Kathren p.111)

The radionuclide that contributes the highest percentage (59%) of the effective dose equivalent commitment is Carbon-14. (Mettler, Moseley p.45) With a half life of 5730 years it is significant that 6 Mci(220 pBq) have been introduced into the atmosphere by nuclear testing, particularly when the natural rate of production is far less than this at about 27 KCi(1 pBq) per year.(UNSCEAR 1982) Figure 2 on the following page illustrates the excess of Carbon-14, produced by weapons testing, in the atmosphere and the upper surfaces of the ocean. Although this large addition is of importance, assessment is difficult due to vast quantities of carbon that have been added to the atmosphere due to the burning of fossil fuels.

Current estimates hold that the dose from fallout of Carbon-14 is estimated as an internal dose commitment of 269 mrad to the whole body and 455 mrad to the bone

marrow. (UNSCEAR 1977) (Kathren p112) The Carbon-14 radioactivity is of limited significance as it will be delivered over thousands of years to several generation. (Mettler, Moseley p. 45)

Figure 2 (Kathren p.112)



Excess Atmospheric C-14 Produced by Weapons Tests. (Adapted from UNSCEAR 1977, p. 119).

More serious aspects of fallout are those containing plutonium, americium and neptunium, as listed in Table 9 along with their properties. Of these, the most significant is Pu-239 due to its long half life and large production amount. By the end of 1973, Pu-239 (half life of 24,360 years) and Pu-240 (half life of 6540 years) represented 320 KCi with 75% of this total being in the northern hemisphere. (Kathren p114) Although greater than 5000 kg (on a mass basis) of plutonium has been injected into the atmosphere, stratospheric levels were less than 1 KCi by 1975. (UNSCEAR 1977). Most of this has fallen onto the Earth's surface,; however, it is estimated that there are still five to ten tons in the atmosphere. (Kathren p.115)

Table 9 (Kathren p.113)

Radiological Properties of Transuranic Nuclides in Fallout.

Nuclide	Half-life	Decay Mode	Comments
Np-239	2.35 d	Beta	Parent of Pu-239; produced by neutron capture by U-238
Pu-239	24,360 y	Alpha	Daughter of Np-239
Pu-240	6540 y	Alpha	Produced by neutron capture by Pu-239
Pu-241	15 y	Beta	Produced by neutron capture by Pu-240; parent of Am-241
Am-241	433 y	Alpha	Daughter of Pu-241

Table 10 (Kathren p.67)

Alpha Activity in Various Foodstuffs.

Foodstuff	Maximum observed alpha activity (pCi/g)
Brazil nuts	14
Cereals	0.06
Teas	0.04
Organ meats	0.015
Flours	0.014
Peanuts, peanut butter	0.012
Chocolate	0.008
Cookies	0.002
Milk (evaporated)	0.002
Fish	0.002
Cheeses	0.0009
Eggs	0.0009
Vegetables	0.0007
Meat (muscle)	0.0005
Fruits	0.0001

Adapted from Mayneord et al. (1958).

Fallout Pathways

Exposure to man occurs mainly through soil from which plants uptake the nuclide where they may be passed on through the food chain to humans. Individuals can be exposed to fallout by either external or internal radiation by ingestion. The fallout material have been incorporated into the soil in which they can be absorbed by plant roots. For that reason, some alpha activity can be found in many of our foodstuffs as shown in Table 10. Throughout the 1960's, elevated levels of radioactivity in food and dairy products were found throughout America. (Blumenthal p.90)

However, the inhalation pathway is estimated to be four times higher than that of ingestion. Inhalation exposure, which should seem to be higher is even less. This is due to the fact that most of the fallout material have fallen out and are entrained within the top few centimeters of the soil. Resuspension of the soil particles but would pose only a minimal risk. Overall, the inhalation risk is five times less than the external radiation dose. (Mettler, Moseley p.45) Much of the fallout material has decayed except that with long half lives which will continue to be a source. The activity ratio in the soil is .25 and will increase to .4 due to nuclide ingrowth.

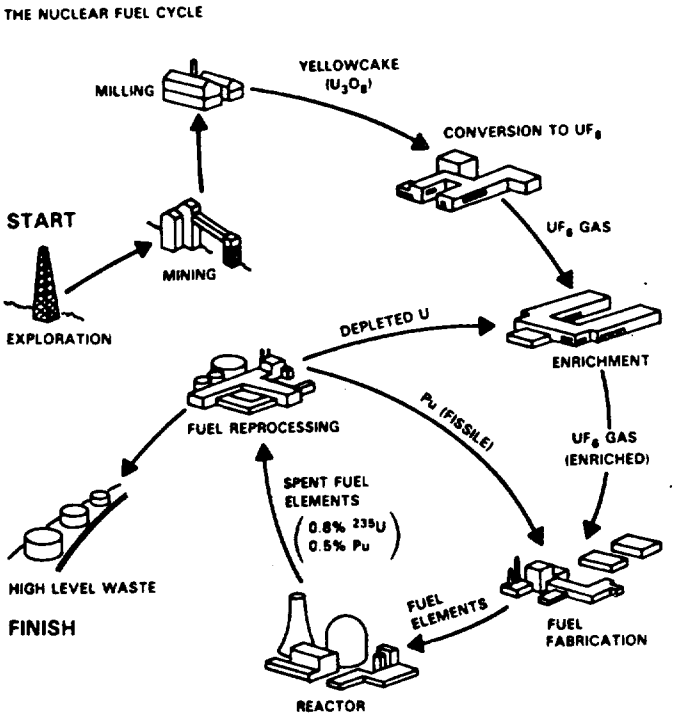
Studies have been done in Nagasaki over which the "Fatman Plutonium" bomb was dropped on August 9,1945, on the amount of fallout in the soil. In 1981 clay and silt samples were analyzed. They found that 97% of the plutonium was retained to a depth of .30 meter, with the rest being dispersed to 2.25 meters. This indicated a migration rate of 1.25 millimeters per year. (14 p.216) This is important in determining groundwater contamination estimates in the United States. Possible exposures will be covered in the plutonium section.

Overall the annual absorbed dose from fallout radionuclides is approximately 4.5 mrem/year to members of the general population which is insignificant in comparison to the 100 mrem contributed by natural sources of radiation. (Mettler, Moseley p.45)

NUCLEAR POWER INDUSTRY

Many people would not expect fallout to be a source of radiation exposure in their lives. However, when the nuclear industry is mentioned, nuclear power, aside from a nuclear war, is what is feared most. There is exposure from the industry, but perhaps not as much as would be expected. To accurately examine exposure from the industry, the whole fuel cycle illustrated in figure 3 below, must be included from mining through waste storage and disposal, as well as environmental dispersion of radionuclides and accidents.

Figure 3 (Kathren p.122)



Fuel Cycle

Initially, the uranium must be mined. When the mine is vented radon and its daughters are released to the atmosphere. This may add up a discharge of 4000 Ci annually just to meet fuel requirements for one light water reactor. (US EPA 1973;

Kathren p.124) As far as liquid releases are concerned, mines may discharge a million gallons of water daily, much of it contaminated, which adds up to about 200 mCi per year of radiation.

The uranium must then be milled, a process which is environmentally significant due to the fact that it leaves behind tailings which must be disposed of and in the past has not been done properly. The process also produces radioactive waste initially when the uranium is crushed and ground, and when it is pulverized and packaged as dry yellowcake when it creates dust and leaves an acid and alkali solvent which is radioactive.

The enrichment of the yellowcake and fabrication of the fuel cause gaseous radioactive wastes which can be controlled and is therefore of minimal concern.

Nuclear reactors represent a large man-made reservoir of radioactivity. (Kathren p.137) The United States has 97 operational reactors with 30 being under construction as of 1985. This figure represents one quarter of the total number of operating plants in the world and more than a third of the world's power generating capacity. The sources of radioactivity in a nuclear reactor include the fuel, which by its nature is radioactive, but really insignificant as a source. (Kathren p.144) The other sources are fission products and activation products as listed in the Tables 11 and 12. Fission in a reactor is the same as that of a nuclear explosion, except much slower. An operating reactor will produce more than 3000 fission products, most of which are radioactive(only those listed in Table 11 are of biological importance).Activation products are produced by the interaction of neutrons with oxygen and hydrogen in coolant water. Also produced are transuranic elements listed in Table 13.

Table 11 (Kathren p.148)

Important Fission Products.

Nuclide	Half-life
Gases	
H-3	12.3y
Kr-85	10.8y
Xe-133m	2.3d
Xe-133	5.3d
Xe-135	9.1h
Solids	
Sr-89	53.0d
Sr-90	28.0y
Y-90	2.7d
Y-91	59.0d
I-131	8.1d
I-133	20.8h
I-135	6.7h
Cs-134	2.0d
Cs-136	14.0d
Cs-137	30.0y
Ba-140	13.0d
La-140	1.7d
Ce-144	290.0d

Table 12 (Kathren p.150)

Important Activation Products.

Nuclide	Half-life
N-16	7s
Ar-41	1.8h
Cr-51	28d
Mn-54	300d
Mn-56	2.6h
Co-58	72d
Co-60	5.4y
Fe-59	45d

Table 13 (Kathren p.152)

Important Transuranic Elements Produced in Reactors.

Nuclide	Half-life	MCi in 1000 MWe Reactor
U-239	6.75d	1,708
Pu-238	86.4y	0.138
Pu-239	24,360y	0.032
Pu-240	6,580y	0.050
Pu-241	13.2y	12.4
Pu-243	5y	22.4
Am + Cm isotopes		1.14
All Actinides		3,614

Source: Nero 1979, p. 37.

The radioactivity released by reactors is dependent on the reactor type. In pressurized water reactors, tritium is a significant source due to the fact that the tritium nucleus is so small, it is able to diffuse through the fuel cladding and into the primary coolant water. When this water is bled off to prevent dangerous build-up of contaminants, an annual maximum of several hundred curies may be released to surface waters. (Kathren p.158) This also occurs during steam generator blowdown which is a rapid withdrawal of water from the secondary system to prevent accumulation of salts or other materials. Fission products may also appear in the coolant waters due to tramp uranium present on the outside to the fuel

cladding. (Kathren p.157). Boiling water reactors produce much less tritium in their coolant waters due to the fact that they do not use boron for reactivity control. Older boiling water reactors, however, do not have effective cleaning equipment for gaseous wastes like newer ones do.

Tritium is the major concern in liquid effluents. Other waste waters are treated through different control systems in which radioactive elements are allowed to decay or are recycled back into the reactor, and then usually directly discharged at a low rate. (Kathren p.156) Reactor discharge limits in the United States are based on "the as low as reasonably achievable" (ALARA) principle, which has been defined as less than 10 mrad from gammas in liquids or 20 mrad from beta radiation. Liquid releases are limited to 5 Ci/year, exclusive of tritium or so that the quantity will deliver an annual dose equivalent of no more than 5mrem. (Kathren p.162)

All gaseous wastes removed from the primary coolant systems, which represent the greatest source of activity releases from a reactor, are stored to allow some of the short-lived radionuclides to decay and then passed through high efficiency particulate filters. Typical releases to the atmosphere are noble gas fission products and activation gases, including tritium, radio-iodine, Carbon-14, and particulates. (Kathren p.160) Releases may be anywhere between a few thousand up to one hundred thousand curies annually, although current technology is bringing that figure down. Despite the fact that this release is large, most radionuclides are very short-lived and decay quickly. One exception is Krypton-85 with a 10.76 year half life and has a tendency to accumulate in the atmosphere. In 1970, the dose to the skin was .02 mrad/year, but by 2000, the predicted dose will be 1.6 mrad/year. Improved controls of effluents may cause this prediction to be an overestimate.

Solid waste such as filters, glassware an evaporator residues are placed in 55 gallon drums and shipped to low level disposal facilities.

A final component of the fuel cycle and the one that many would argue, is the most important and hazardous is the storage and disposal of waste. In discussing waste, there are really two classifications: defense and commercial with distinctions being made between high level, low level and transuranic. High level waste results from the reprocessing of spent fuel or is the spent fuel itself. Tranuranic(TRU) wastes are byproducts of fuel assembly, weapons fabrication and reprocessing. The TRU wastes have low levels of radioactivity, but contain isotopes that have very long half lives (over 20 years). Low level wastes are all other wastes besides high level or TRU, most of which is bulky wastes containing very low levels of radioactivity. The greatest amount of defense waste is at Hanford, Washington where 11,000 cubic meters of TRU is stored in leaking tanks. This is not seen as a direct threat to the population in the area at the present time.

Another source of waste and a potential source to future populations are the nuclear reactors which are no longer in operation. Possibilities for shut down reactors include : 1) Decontamination and dismantlement of the facility in which all radioactive material is removed and disposed of properly. 2) Entombment in which concrete and steel barriers are erected to seal in radioactive components. 3) Mothballing under which some decontamination is done, but the plant is closed and guarded indefinitely. If not handled properly, the old reactors could become a problem and add to the exposure rates of portions of the general population.

Accidents

Accidents play a part in radiation exposure, although they affect only a small portion of the population. Three Mile Island and Chernobyl are the most significant. In the former, activity releases were estimated to be 2.5 million curies which fortunately consisted of mainly short-lived noble gases. Doses to the nearby population ranged from a collective population dose equivalent from 300 to 3500 person rem. (Kathren p.168) The maximumally exposed individual dose was estimated at less than 100 mrem. Many studies have been done, and the conclusion is that any effect on the population will be minimal.

The Chernobyl accident which occurred in May of 1986, on the other hand, was much more serious and affected a greater number of people. The amount of activity released has made this the worst nuclear incident in the history. Four and a half million curies of Iodine-131 alone were released in the first twenty four hours, with 7.3 million more released in the following ten days. Despite Perestroika, information regarding the accident is not easily attained. The Soviets deny many of the statistics detailing fatalities and injuries. There is a 1000 square kilometer area which will probably never be inhabited again. (Gale p.401)

Other accidents include the release of 6 Ci of plutonium at the Rocky Flats plant near Denver in 1969. Fortunately, the environmental contamination was contained to the site. This is true of most accidents in the weapons industry regarding plutonium which does not become widely dispersed in the environment and remains in the top several centimeters of the soil, as evidenced in the earlier example from Nagasaki. (Kathren p.169)

Exposure

Despite all the radioactivity associated with nuclear power, the main biologic and environmental concern for exposure to man from nuclear power is any accidental releases through migration into water sources or into the atmosphere. Dose exposures from the nuclear industry are shown in Table 14 on the next page.

People living near the site are of course most concerned, but under U.S. regulations, the absorbed dose to the population at the site boundary must be less than 5 mrem. This is the to be the maximum dose for an individual who spends 365 days of the year at the site boundary. (Mettler, Moseley p.46). The Environmental Protection Agency has also set a limit of 25 mrem per year to the general population from all activities in the nuclear power industry. (Hendee p.44) Current estimates show that actual annual doses are about 1 mrem. (Hendee p.44) In 1980, the effective dose equivalent for nuclear power worldwide was estimated at .01 mrem, which is only .005% of the average exposure to natural sources of radiation. However, due to ingrowth of radionuclides through decay and if growth in the nuclear continues, this source could eventually contribute up to .05% of the radiation exposure that natural sources contribute.

After review of all sources of radiation exposure in the life of an individual, nuclear power and fallout seem to actually play only a very small role, although the potential for exposure does exist.

TABLE 14 (Pochin p.70)

Collective whole body doses, partial body exposures and occupational fatality rates occurring at different stages of nuclear power production process

Stage	Whole body exposures (man.rem/MW(e)y)		Partial body exposures	Fatal occupational accidents and diseases per 1000 MW(e)y
	Population	Occupational		
Construction of installations	-	-	-	0.25
Uranium Mining	-	External, to miners 0.1	Lung, miners	0.4
Milling and processing	-	(Probably less than 0.1)	Lung and hands slight	say 0.1
Fabrication and enrichment	-	-	Probably slight	-
Reactor operation	Liquid wastes 0.002 Gaseous wastes 0.1	From activation and fission products (external and tritium) 2.0	-	0.02
Reprocessing plants	Liquid wastes 0.1 Gaseous wastes 0.25 C14 1.0*	From activation and fission products (mainly external) 2.0	Occupational, to lung and other tissues occasionally Public, to skin, intestine, thyroid and bone for small groups	0.02
Other fuel steps	-	0.03	-	-
Transport	0.004	0.005	-	0.003
Accidents	0.05	-	-	
Total	1.5	+ 4.2	See text	0.8
Total (genetically significant)	1.5	+ 2.7	-	

*From reactors; discharges from reprocessing plants at present uncertain. Total dose commitment to future: 0.05 in first 30 years.

Epidemiology

Before analyzing the risk that plutonium poses, some general epidemiologic explanations are necessary. Acute effects due to high dose rates are not of significance in dealing with the risk to the public from plutonium, however, they will be considered in the next section to prove a point. The physical effects of radiation occur in a fraction of a second, whereas the biological effects on the cells may not be affected for years. (Blumenthal p.82) The main concern is with low doses(below 100 rads) of the element with which cancer induction is the most important somatic effect and will be concentrated on throughout this report. (Mettler, Moseley p.74) However, it should be noted that "there is convincing data that cancer induction due to radiation occurs at high doses, but at low doses (only a few rads), the evidence is statistical and cannot be attributed with certainty."(Blumenthal p.98)

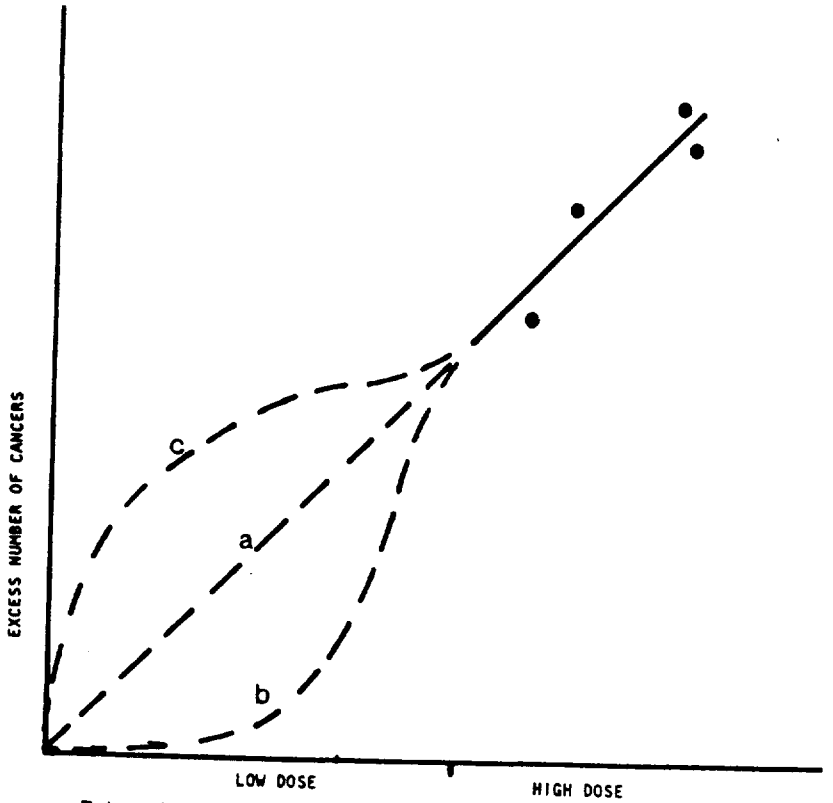
Although the induction of cancer is a process of several stages. The first of which consists of a low dose of a carcinogen being applied to a target cell or tissue. This initiator is assumed to act on the DNA, perhaps forming an oncogene. (Mettler, Moseley p.76) At this point, "steplike changes" that convert the initiated cell into an actual cancer may occur through the action of a promotor which is a non-carcinogenic chemical that enhances the production of malignant tumors. (Mettler, Moseley p.77) The ionizing radiation in this case would be the low dose of the carcinogen.

The effects of low doses are difficult to assess, particularly those that need to be studied over long periods of time, as is the case with cancer induction. Low dose studies on human populations have been inconclusive. Therefore risk estimates are obtained by extrapolating from animal to humans or from high dose effects(as is the

case with accidents) on humans to low dose effects. Statistical accuracy can only be obtained with large numbers of people or animals exposed at a known dose. Low dose studies on human populations have been inconclusive. Radiation induced cancer is difficult to detect because the number is small and cancer from natural causes is so prevalent. Cancers induced by radiation are indistinguishable from those induced by other causes. The inference that radiation is the cause of cancer is based only an excess of cancers above the natural average.(Blumenthal p.98) Cancer from natural causes is so prevalent, (16% for both fatal and nonfatal), that the likelihood that an individual will experience cancer is one in three. (Hendee p.15) Radiation induced cancers are not as common, so for testing purposes, animals, due to cost and the fact that doses can be controlled have been used. (Hendee p.15)

After animal data or high dose human data is obtained, the risk is estimated by using the dose response model, the use of which requires knowing the shape of the curve at low doses and low dose rates. This is illustrated in Figure 4. Curves a, b, and c are possible extrapolations. The a shape(linear), used typically, is basically just scientific speculation and constitutes "the low dose extrapolation problem". There is considerable evidence that the "B" curve is the proper one, however, not enough to convince many people. Animal studies are done using high dose rates because there will be some effect that can be studied. Doses are high enough to inflict some type of damage on organs. To study low level radiation, there would have to be three million animals and a large control group in the study, just to assess the risk of one induced cancer per million population. This is study would have to be based in the assumption that no spontaneous tumors would occur in the control group. (Hendee p.94) The problems with studying this many animals are

Figure 4 (Hendee p.15)



Extrapolation of dose-effect data.

obvious. Their identity, randomization and living conditions would have to be controlled. Errors in handling and feeding could easily produce enough variation in the data to prevent the identity of a small carcinogenic effect or induce conditions which favor cancer induction more than others. (Hendee p.94) Therefore, low dose cancer induction cannot be predicted precisely and "may be transcientific, residing in the public and scientific community's attitude towards the issue." (Hendee p.94)

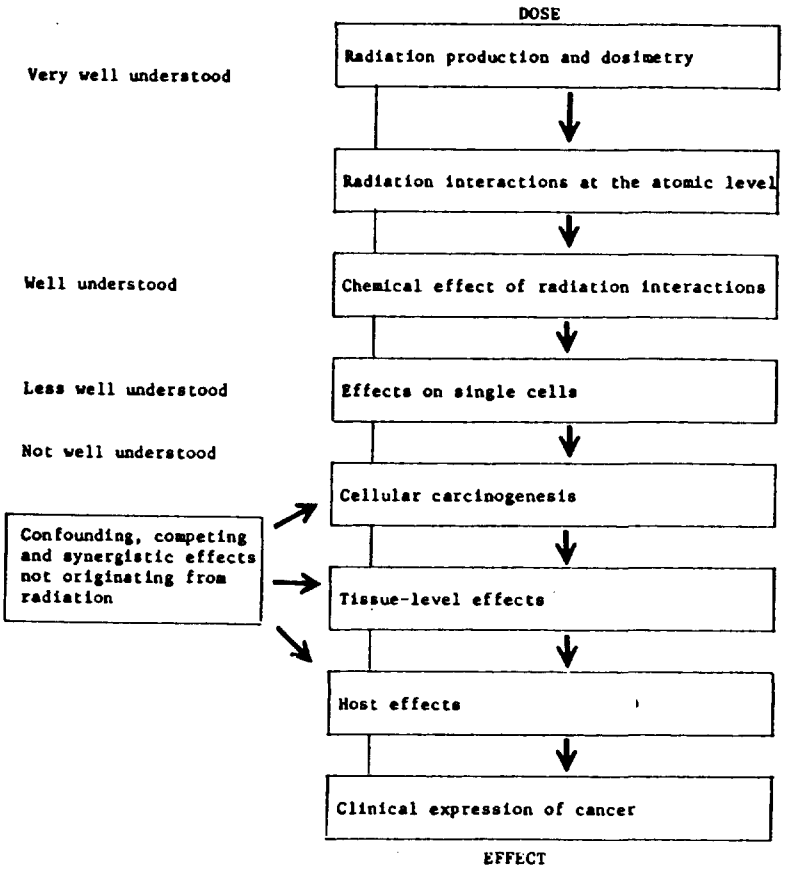
Another problem with extrapolating animal data to humans is the fact that animal life spans are shorter, animal tumors are morphologically different from human tumors, the body systems are very different particularly in smaller animals such as

mice. Therefore the data which is relied on more heavily is that which comes from larger mammals such as dogs.

Other things of consideration in cancer induction include the stochiastic effect which means that increasing radiation dose, means increasing the probability of an effect but does not change the severity of the effect. Also there is assumed to be no threshold level; even small doses are assumed to have the ability to cause cancer. (Mettler, Moseley p.74)

Figure 5

(Hendee p.78)



. Block diagram of the steps leading from dose to effect. The level of understanding of the fundamental processes involved generally decreases as the complexity of system increases.

As shown in the dose/effect figure(Figure 5), there are aspects of the radiation dose/effect process which are not well understood. Radiation effects vary depending on the type of radiation and its intensity. Cellular response to radiation

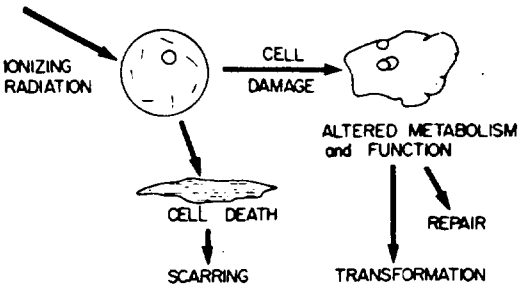
also varies and there are many questions about the radiosensitivity and radioprotective properties of the cells. For example, at low doses the critical part of the cell which is injured is the DNA which does repair itself quickly up to single acute doses of 10 rads. (Hendee p.17) Such data on other aspects of cell damage is not available yet, although as shown in Table 16, scientists have a general idea about the degree of radiosensitivity of normal cells.

Table 16 (Mettler, Moseley p.18)

Radiosensitivity of Normal Cells

Radiosensitivity	Cell Types
Very high	Lymphocytes
	Immature hematopoietic cells
	Intestinal epithelium
	Spermatogonia
	Ovarian follicular cells
High	Urinary bladder epithelium
	Esophageal epithelium
	Gastric mucosa
	Mucous membranes
	Epidermal epithelium
	Epithelium of optic lens
Intermediate	Endothelium
	Growing bone and cartilage
	Fibroblasts
	Glial cells
	Glandular epithelium of breast
	Pulmonary epithelium
	Renal epithelium
	Hepatic epithelium
	Pancreatic epithelium
	Thyroid epithelium
	Adrenal epithelium
Low	Mature hematopoietic cells
	Muscle cells
	Mature connective tissues
	Mature bone and cartilage
	Ganglion cells

Figure 6 (Mettler,Moseley p.14)



Possible cellular changes following exposure to ionizing radiation. If radiation exposure is high enough, cell death and ultimate tissue scarring may result if the organism survives. If the cell recovers on an acute basis, there remains a possibility of altered metabolism and function, which may be repaired, or there may be transformation to a carcinogenic cell.

Damage to cells, as illustrated in Figure 6, can occur as a result of direct hits by ionizing radiation, but can also occur indirectly. The radiation may pass through

the body without hitting any cells; part of cells may be hit and damaged and then repair themselves. After radiation hits the cell, it may be damaged in such a way that it cannot reproduce itself or it may be destroyed. A fourth alternative is that the cell may be damaged and survive to produce a clone of damaged cells.

The studies done also do not consider many of the variables causing synergistic effects which would be present in real life. These include exposure to other oncogenic agents, immunological status, and the state of the DNA repair mechanism.

A final area which must be examined is that of birth abnormalities and genetic effects due to radiation. Effects of the former are dependent on the stage of development. In the embryonic stage, it is important to note that rapidly dividing cells are very radiosensitive and the smaller number of cells during that stage make each on extremely vital for development. Due to these facts, it highly probable that radiation will detrimentally affect developing embryos. This is difficult to quantify with any certainty because 4 to 6% of all live births have some abnormality present and those produced by radiation are no different than those produced spontaneously. (Hendee p.19) There have been no birth defects in the population exposed in Hiroshima (Gale p.401); however, researchers in West Germany, over which Chernobyl's radioactive cloud moved, have found a striking deviation in their infant mortality rate after the May 1986 accident. The infant mortality rate was found to be increasing exponentially in areas which experienced greatest fallout. (Luning, et al. p.1081) The Soviet Union denies any birth defects in their country associated with the accident. (Gale p.401)

Genetic effects are generally not well understood overall, so exact effects of radiation are hard to predict. In animals, genetic effects have been found to be

associated with dominant, recessive and irregular types of genetic mutations and small chromosomal aberrations. Studies of the atom bomb survivors have found no significant effects on the first or second generations. A study trying to quantify the risk, estimates that if each generation receives one additional rem to the gonads, .006-.110% of the population will incur radiation-induced genetic malformations after many generations have passed. (Hendee p.19) These figures may change after genetics becomes better understood.

Acute Radiation Hazard

Radiation sickness, name Acute Radiation Syndrome (ARS) is the product of whole body does of a few hundred rem in a short amount of time. This sickness produces nausea and vomiting initially and then after a few week, produces diarrhea, emaciation, loss of hair, fever, sore throat, and subcutaneous bleeding. At doses of 500 rem, half of the population exposed would die. At doses of 1000 rem, infection and bleeding due to failure of the hematopoietic system will begin and death will occur within a month. Doses between 1000 and 10,000 rem will severely affect the G-I system and death will occur within a day due to ulceration and bleeding in the G-I tract. Doses above 10,000 rem will damage the cells of the nervous system and death will occur within an hour. (Hendee p.14)

Doses of these levels are highly unlikely for any member of the general population to be exposed to. Low level radiation is of primary concern. Low level radiation constitutes an absorbed dose of 10 rem or less over a short period of time or 50 rem in 10 years. As discussed earlier, the dose to the general population due to background radiation is 100 mrem/yr(.001rem) with total doses to an average person